MEASUREMENT OF THE TIMING JITTER BETWEEN A TIME REFERENCE SIGNAL AND EUV-FEL PULSES AT XFEL/SPRING-8

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Abstract

The SCSS test accelerator was constructed and user experiments using SASE-FEL light in an extreme-ultraviolet (EUV) region have been performed at SPring-8. It is necessary to distribute an accurate timing signal both to accelerator components and experimental instruments at the test accelerator. We developed a trigger system aiming at a timing jitter of less than 100 fs. The time jitter between the reference timing signal and a beam-induced signal from an RF-BPM cavity was measured. The jitter value was nearly 50 fs in rms. However, this value was timing of the electron beams at the BPM position just before an undulator section and not an arrival timing of the EUV light pulses at an experimental end station. Therefore, we employed an in-vacuum fast photo diode in order to directly observe the EUV light at a wavelength form 50 nm to 60 nm and to detect the arrival timing at the end station. The measured time jitter was 2.5 ps in rms, which was limited by the time response of the photo diode. Even thorough the resolution of the time jitter did not reach to 50 fs, the system is still usable to verify trigger delay values for user experiments. This fast timing measurement method using the in-vacuum photo diode is still a pioneer of optical technology in an FEL field.

INTRODUCTION

The x-ray free electron laser facility at the SPring-8 campus (XFEL/SPring-8) [1], for which generates coherent and extremely short pulse x-rays having a wave length of 0.1nm, a peak power of 1 GW and a pulse width of about 30 fs, is under construction. The XFEL facility based on SCSS concept [2] to make a machine length short consists of an electron injector with a low-emittance thermionic gun for adiabatic velocity bunching of electrons, C-band high-gradient accelerators and short period in-vacuum undulators. The facility is about 700 m long. Because of the SCSS concept, an electron pulse with a 30 fs pulse width and a 3 kA peak current for non-linear laser amplification for the undulator section is formed along the off-crest acceleration parts of an injector for velocity bunching and 3-stage bunch compressors for magnetic bunching. For generating stable SASE-FEL light, timing accuracy is required around sub-picoseconds in the crest acceleration part of a C-band main accelerator to obtain energy of 8GeV, and necessary less than 50 fs at a C-band correction cavity in the off-crest acceleration parts [3]. Therefore, the timing system for the XFEL has been developed to keep the constant peak current with the 30fs pulse width.

The SCSS test accelerator, which was constructed in advance of the XFEL, has been generating stable Extremely Ultra-Violet laser (EUV-FEL) light. The SCSS test accelerator has been used to evaluate technical elements for the XFEL, and for user experiments. One of the prominent user experiments is a pump-probe experiment using the SCSS accelerator and the XFEL. These experiments practically use the feature of a coherent short-pulse, which has light pulse widths of sub-picoseconds in the SCSS test accelerator and a few-tens of femtosecond in the XFEL. Highly accurate timing signal with an accuracy of under several tens femtosecond is necessary to withdraw time determination ability by the short pulse widths in these experiments as well as for the parts of the accelerator to generate a stable laser. In the SCSS test accelerator, the timing jitter value, as which is described in the section below, between a reference timing signal and a beam-induced signal was measured by using an RF-BPM (Beam Position Monitor) cavity. However, an arrival timing of the EUV light pulses was not measured. The timing jitter of the EUV light must be measured, since the object of the test accelerator is generating the light for user. The relation between the time jitters of the electron described above and the EUV light should be understood to make the machine operation parameter of the test accelerator clear. Furthermore, the method to measure the timing jitter of the X-ray laser light in a femtosecond region, even the EUV light, is not presently established, and should be established. We considered a simple timing jitter measurement method of the EUV light using an in-vacuum fast PD (photo diode), as the first step to establish the jitter measurement method for FEL light. In this paper, we describe experiments to measurement a timing jitter of the EUV-FEL light pulses, and its results.

TIMING SYSTEM OF SCSS TEST ACCELERATOR

Outline of Time Reference RF Signal System

The outline of a timing system for the SCSS test accelerator and the accelerator, itself, is shown in Fig. 1. Electron beams are generated by the thermionic electron gun using a CeB6 single crystal. The beam energy is boosted by 238 MHz, 476 MHz, S-band (2856 MHz) and C-band (5712 MHz) accelerators, up to 250 MeV. Moreover, the electron beam bunch length is shortened

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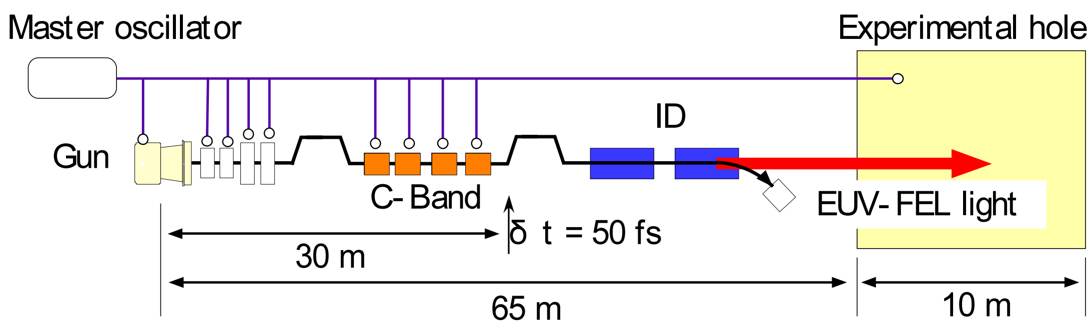

Figure 1: Outline of the SCSS accelerator and timing system.

from 1 ns to sub-picosecond by velocity and magnetic bunching processes through sub-harmonic acceleration cavities and the magnetic chicanes.

The master oscillator [4,5] generates 238 MHz, 476 MHz and 2856 MHz time reference RF signals, as well as a 5712 MHz reference signal, and is placed near by the electron gun. The reference RF signal is distributed at RF and timing components from the master oscillator toward an experiment hall along 70m of the accelerator. The signals are distributed through coaxial cables of HF-15D (Hitachi Cable Ltd). Its temperature coefficient is around 8 ppm/K. The electron beam is accelerated by this reference RF signal, besides, the signal is also used as timing signal to identify the arrival timing of the FEL light pulses at the experimental hall.

The RF and timing components around the SCSS accelerator should be synchronously driven by the reference signals to obtain a stable electron beam for generating stable coherent light.

Arrival Timing Jitter of an Electron Beam

The accuracy of the time reference system at the SCSS test accelerator was examined by measuring the timing jitter between a 4760 MHz signal made from a time reference signal and a beam-induced field in the 4760 MHz intensity detection cavity of a RF-BPM [5]. The 4760 MHz signal was made by the heterodyne method which is mixing the 5712 MHz and 925 MHz (238 MHz x 4) signals. The result of the timing jitter measurement was 46 fs in rms at the RF-BPM position just before an undulator section. This value shows evidence of which the time reference system satisfies the required timing accuracy for generating a stable EUV-FEL, even the case of the XFEL.

However, the value of this measurement is the arrival timing of the electron beam and not an arrival timing of the EUV-FEL pulses in the SCSS accelerator. It is necessary to measure the arrival timing of the EUV-FEL pulses at the experimental end station for users, especially for pump-probe experiment users.

ARRIVAL TIMING JITTER OF EUV-FEL LIGHT

Measurement Using Phosphor of Ce:YAG Crystal

For a pump-probe experiment, the arrival timing measurement accuracy between the reference RF signal and the EUV-FEL light pulses is required up to less than1 ps at the experimental end station, because of the sub-picosecond duration of the EUV-FEL pulse. As a first measurement system to check the arrival timing of the EUV-FEL, a phosphor screen of a Ce:YAG crystal [6], which is usually used to observe a position of the EUV-FEL light at the experimental station, was employed. The canter wavelength of the Ce:YAG fluorescence is about 530 nm which is adaptable to measure with a Si-PD. A fast Si-PD (ET-2030, Electro-Optics Technology), which

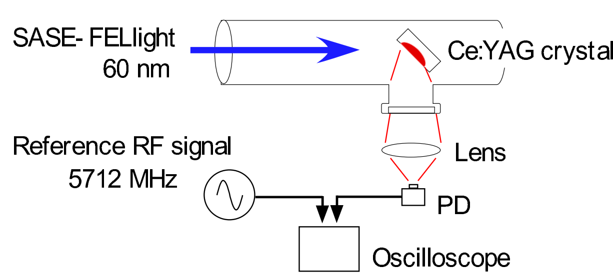

Figure 1: Configuration of measurement system with the Ce:YAG crystal.

is usually used to determine a rough arrival timing of an ultrafast laser pulse generated by a Ti:sapphire laser, was employed for our arrival timing measurement experiment of the EUV-FEL. The measurement system using the Ce:YAG and Si-PD is illustrated in Fig. 2. The Ce:YAG crystal was installed in a vacuum chamber and settled with an angle of 45 degrees toward the EUV-FEL and the Si-PD placed at outside position of the chamber for observation, respectively (The fluorescence was taken out through a viewport at an angle of 90 degrees referred to the axis of the EUV-FEL). The fluorescence was focused

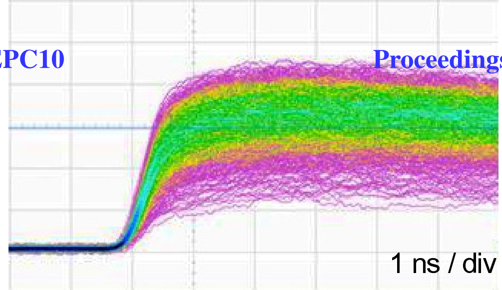

Figure 3: The output wave form of the Si-PD shown in Fig. 2.

on the Si-PD by using a spherical lens. The timing jitter was measured with the Si-PD and a wide band oscilloscope (DSO81204B, Agilent Technology, Band width 12 GHz).

The waveform of the Si-PD is shown in Fig.3. The rise time and the width (FWHM) of the pulse outputted from the Si-PD are measured to be 400 ps and 400 ns, respectively. However, we could not exactly measure a timing jitter owing to shot by shot signal fluctuation of the EUV-FEL pulse. In the case of the SCSS test accelerator, the output fluctuation of the EUV-FEL light is about 10% in rms, because of the generation principle of SASE along an undulator section. An amplitude fluctuation of the Si-PD signals was bigger than the 10% SASE fluctuation. Why the large fluctuation was occurred, because this fluctuation could be a superimposed signal of the EUV light position (pointing stability) and distribution variations, and the intrinsic SASE fluctuation on the phosphor screen. Furthermore, the optical system guiding the fluorescence from the screen to the Si-PD did not well transmit the fluorescence image at the emission point on the Ce:YAG crystal, because of the optical aberration and misalignments of optical components, such as lenses. Therefore, the amplitude fluctuation caused by the position and distribution variation of the EUV-FEL light was enhanced by the optical system.

The timing jitter was roughly estimated to be t 30 ps by comparing the signals from the Si-PD with the 5712MHz time reference signal. This value did not as small as the value expected from that of the measurement using the RF-BPM. This measurement accuracy could be considered to be the limit of detection accuracy by using the measurement system using the Si-PD. The rise time of 400 ps could be limited by the time response of the Si-PD and the pulse duration of 400 ns could be decided by the relaxation time of fluorescence in the Ce:YAG crystal [6]. A much faster measurement system is necessary to obtain sub-picosecond time accuracy in accordance with our requirement.

Direct Measurement of EUV-Light

To increase accuracy of a time jitter measurement system, an in-vacuum fast PD was employed in order to directly observe SASE-FEL light of a 60 nm wavelength without any optical elements which degrade time resolution. The PD (AXUVHS10, International Radiation Detectors Inc.) has a fast rise time of nearly 50 ps which is about one order of magnitude faster than that of the Si-PD. The PD was installed in the vacuum chamber, and the signal from the PD was taken out with a coaxial cable through a feedthrough coaxial connector on the vacuum flange. This coaxial cable in the chamber is also adaptable to vacuum environment. Figure 4 shows the experimental setup around the PD. Since the PD can directly measure the EUV-FEL light with high peak power, high noise to signal (S/N) ratio is expected in the measurement system. The timing jitter was measured with the wide band oscilloscope as same as mentioned above.

The measurement result is shown in Fig.5. The rise time and pulse width (FWHM) were measured to be almost 90 ps and 450 ps, respectively. The fluctuation of the observed light intensity was less than 10%. The effective area of the PD to detect light is 30 μm in diameter. This size is small enough compared with the transverse beam size, 10 mm in diameter, of the EUV-FEL light. This small size as well as removing the optical components was effective to reduce the observed amplitude fluctuation at the previous experiment.

The timing jitter being 2.3 ps in rms was measured by the PD. This value is almost close to the required value, however, it is slightly not enough. We expect that the actual timing jitter between the EUV-FEL light and the reference RF signal could be several tens femtosecond which were shown in the time jitter measurement of the electron beam. The measurement system using the in-vacuum fast PD did not show ability to observe the actual jitter, but this system is still useful to determine the rough

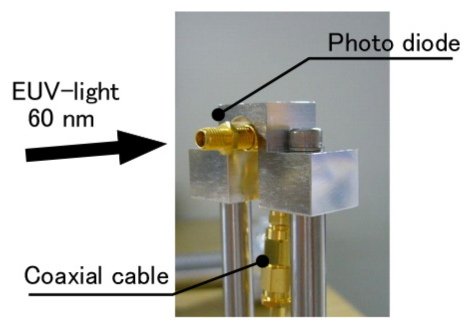

Figure 4: Photo of the in-vacuum fast PD.

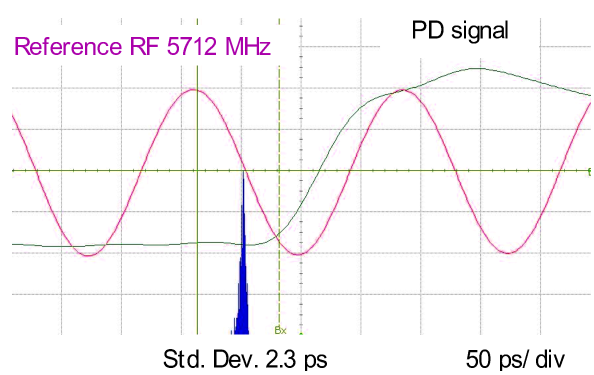

Figure 2: Waveforms of the reference RF signal and detected signal by the PD. The Std. Dev. is 2.3 ps timing jitter in rms.

arrival timing of the EUV-FEL light for user experiments, even in the case of the XFEL.

SUMMARY AND FUTUER WORK

We tried to measure the timing jitter between a time reference RF signal and EUV light pulses at the experimental end station of the SCSS test accelerator. A time jitter measured by the measurement system using an in-vacuum fast PD was 2.3 ps in rms. It did not reach to a resolution of 50 fs which was a timing jitter measured between a reference RF signal and electron beams. 2.3 ps is the limit of detection accuracy of the measurement system. Even thorough the system resolution to measure arrival time of the EUV light is not less than one picosecond, the system is still usable to verify trigger delay values for user experiments. This fast timing measurement method using the in-vacuum photo diode is a pioneer of optical technology in an FEL field.

We will try to develop a measurement system with sub-picosecond resolution for the timing jitter of the EUV light. A scintillator which has an extremely fast time response of fluorescence emission, for example a ZnO crystal [7], is now investigated as the next phosphor screen. It has already been confirmed that response time of the scintillation is less than 50 ps by rough measurement using a streak camera of FESCA200. The FESCA200 is able to measure a pulse width of 200 fs. We expect that the sub-picosecond resolution could be obtained by a measurement system using the FESCA200 and the ZnO crystal.

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